

# Modelling the calvarium diploe

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*The paper presents the effects of computer modelling of the inner structure of the calvarium from CT scans using MeeSoft Image Analyzer software. This software generates a model image, which can be enlarged and viewed from different angles without visible distortion or blurring of the contours. Similar manipulation with the original CT scan produces destructive effects, which hinder visualisation of the anatomical structures.*

**Key words:** anatomical modelling, volumetric models, cranial bones

## INTRODUCTION

The bones of the calvarium consist of the outer and inner layers of compact bone separated by the cancellous bone termed the “diploe”. The diploe is full of small cavities and sparsely distributed channels, which are situated between bony trabeculae. The interconnecting channels traverse the diploe and communicate with the veins of the skull [2, 5, 12].

In dry skulls both the cavities and channels are filled with air, as these are empty spaces arranged in the manner of tiny compartments. Their organisation changes in different regions of the skull and can be altered in some pathological cases [8]. The structure of the bony elements can be visualised by computer assisted tomography (CT). This technique produces a stack of CT scans imaging consecutive sections of the skull. Hence three-dimensional reconstruction can be involved in anatomical study, contributing to spatial imaging of the regions of the skull examined. Modern visualisation techniques allow data to be viewed as orthogonal or oblique sections, as a volume or surface rendered object [16]. Orthogonal sections provide a general overview of image data sets and allow the operator to compare images visually, while oblique sections can extract slices at any arbitrary orientation within a volumetric data set. Medical imaging systems have evolved to the point where it is possible to see certain ana-

tomical structures in very fine detail [14]. In anatomical study, however, it is not always necessary to perform a full three-dimensional reconstruction of the entire structure but only to examine selected sections.

The aim of this work was to generate a computer model of the section through the calvarium, which can be viewed at varying angles and enlarged without observable deformities. Particular attention was focused on modelling the diploe and diploic channels to gain better results in their visualisation than in normal CT scans.

## MATERIAL AND METHOD

Modelling of the diploe and the adjacent layers of the compact bone was based on CT scans of the human dry skull. Spiral computed tomography was used to produce transaxial images. Each CT scan was a two-dimensional greyscale image created in DICOM format. An intensity window setting technique was used in viewing the CT scan to provide adequate contrast and detail within the sections of the calvarium imaged. The window width was experimentally set to obtain a good quality of image display [1, 4]. Original CT scans were converted from DICOM format to bitmap files. This file served as a background to generate a model image of the structure of the inner calvarium structure.

A computer model of the section through the calvarium was generated by MeeSoft Image Analyzer software (<http://meesoft.logicnet.dk>) [15].

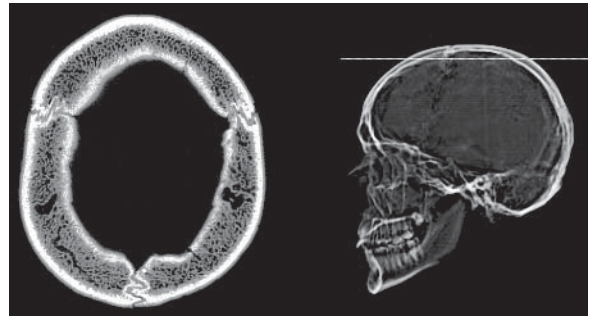
Dark patches extracted from the image correspond to hollow places in the diploe, while white areas indicate layers of compact bone. Intermediate intensities of grey represent loose or denser structure of the diploe. As was mentioned earlier, in CT images are displayed in greyscale and therefore the model image was created in shades of grey.

Modelled images can be enlarged and viewed at different angles in the computer program (Image Analyzer). This manipulation enables more details to be perceived and enhances the spatial imaging about the spatial relation of the structures analysed.

In the final stage of imaging the brightness and contrast of the model were adjusted. Thus the image was subjected to gamma correction if necessary and graphic filters (adaptive smooth/sharpen filter, noise reduction) were used to improve the quality of the image.

## RESULTS

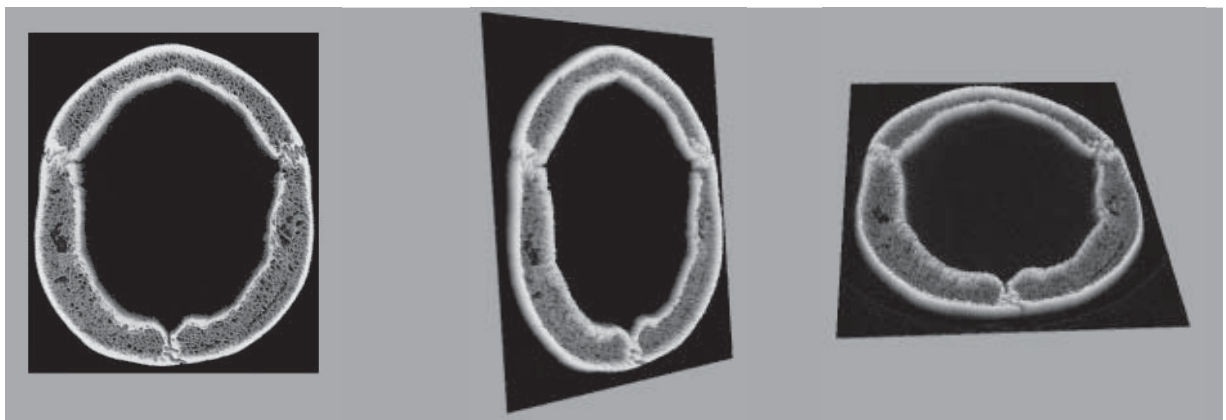
Images of the calvarium obtained from computed tomography served to generate a spatial model of the anatomical structure of the diploe and related layers of compact bone (Fig. 1). The resultant model images provide accurate and realistic representation of the horizontal section through the calvarium. One may easily perceive and trace diploic channels, which are vividly distinct from diploic pores and interstices between bony trabeculae. These structures look different, in particular, as shown by Figure 2, when the image is rotated. The spatial positioning of the model image gave perspective visualisation of the diploic structure. Thus the height or depth of the anatomical



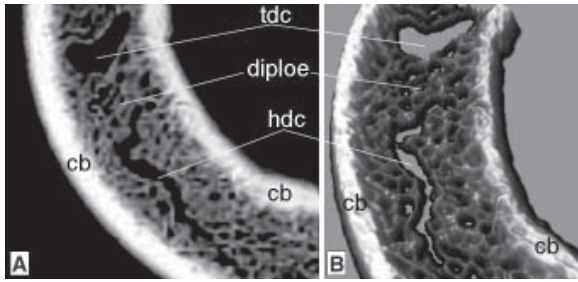
**Figure 1.** Axial CT scan of the cranium and the topogram showing the section level.

components of the diploe was reconstructed. The model image reflected the shape and the surface configuration of the anatomical structures analysed. Moreover it captured the physical properties of the diploe, which could be described as rough, porous and irregular. Local changes of bone mineral density found representation in the model in the form of varying luminance. This resulted from the distinct distribution of thinner or thicker trabeculae of spongy bone within the diploe.

The thickness of the section of the calvarium modelled enhances its optical property and this result from the shades of grey of the original CT scan, which in turn correspond to the bone density. Thus the model image of the sectioned calvarium can be termed a surface model, because it represents a conformation of the texture. This means that more compact regions of the calvarium seem to be higher in the model than those with a loose structure. All together the dense structures produce boundary details in the model, while the porous ones fill the interior of the section.



**Figure 2.** Model images — section through the calvarium viewed at different angles. Lighter parts of the model image represent compact bone and the darker (grey shades) spongy bone. Black fill represents the reference plane (background).



**Figure 3.** Enlarged original CT scan (A) and modelled image (B) of the bone structure within the horizontal section of the cranium; tdc — transverse view of diploic channel, hdc — horizontal view of diploic channel, cb — compact bone of outer and inner table.

A close-up of the features (such as diploic channels) visible in Figure 2 is shown in Figure 3. The enlargement of the model image produced an apparently sharper and more detailed microarchitecture of the three-layered structure of the cranial bone than did the original CT scan (Fig. 3). In the enlarged model image the diploe is represented more precisely than in the original enlarged CT scan, which is blurred. Moreover, the magnified model section through the calvarium can be viewed from different angles without visible deformation of the structure imaged. The model image of the diploe revealed a number of small cavities and channels of various depth and orientation. The outer layers of the compact bone are preserved in the model as a condensed texture that limits the diploe.

## DISCUSSION

A typical three-dimensional or volume model is created from a set of images or segmented contours. The proposed model is based on conversion of a single flat image (a two-dimensional CT scan) to a three-dimensional composition by shifting CT scan texture. This simulates the third dimension, which is generated from a depth colour map of the image. The difference between the orthogonal view of the original CT scan and the model image is most pronounced in the observable perspective. Apparently flat, the texture of porous diploe visible on the two-dimensional image becomes the convoluted surface with many depressions and elevations expressed by the model image. Owing to the opportunity to manipulate the model on the computer screen the structure may be observed from different angles without distortion of the image. Another facility of the proposed model is lack of extensive blur when the image is enlarged. Usually CT scans of low resolution are blurred when they are

enlarged and this significantly reduces the quality of the image. The proposed model therefore has a high degree of fidelity to the contours and is able to handle complex structures. It helps to interpret structures on enlarged images without loss of detail in the image resulting from the blur effect.

Anatomical models of the diploe can be helpful in studying morphological changes related to ageing or pathological processes that involve the inner structure of the calvarial bones. In some pathological cases (such as sickle cell anaemia) the diploe shows lamellation and the diploic space has the appearance of long thin vertical striations [6, 10, 11, 13]. Enlarged model images can show the extent of potential defects within the diploe or the dissection of the cranial bones better than small original plain CT scans.

The other feature of the model is that it enables the structure to be viewed at various angles, while the original plain CT scan is only an orthogonal representation of the structure. Thus perception of the image facilitates estimation of the spatial relationships between different structures such as diploic channels. Spatial visualisation of biological objects may help in gaining a better understanding of their conformation and of the relationship between structural components. A multi-dimensional interactive display of CT scans contributes to this process and helps in the construction of computer models of biological objects. Modelling methods based on ray tracing techniques and volume rendering allow realistic images to be generated which map anatomical structures in a virtual environment [3, 7, 9].

The Image Analyzer software is capable of modelling anatomical structures and correcting quickly any graphical defects. This computer program can be extremely useful for viewing and for accurate image manipulation.

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